(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 933 903 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
04.08.1999 Bulletin 1999/31

(51) Int Cl.^{6}: H04L 27/26

(21) Application number: 99300701.2

(22) Date of filing: 29.01.1999

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 30.01.1998 JP 1989198

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(54) Suppression of phase noise in multicarrier reception

(57) An input OFDM signal is frequency-converted to a signal having an IF (intermediate frequency) by a tuner (101) and a local oscillator (102), and the signal is converted to a complex base-band signal by an IQ demodulator (104). A phase noise suppression circuit (105) detects a phase variation of the complex base-band signal and corrects it to suppress a phase noise of the local oscillator (102). An output of the phase noise suppression circuit (105) is subjected to FFT processing in an effective symbol interval of a one-symbol interval in an FFT circuit (106) to thereby obtain received data of each subcarrier. Since the phase noise of the local oscillator (102) is reduced by the phase noise suppression circuit 105 before the FFT processing, both a CPE and an ICI are reduced from the output of the FFT circuit (106). The output of the FFT circuit (106) is sent to a demodulation circuit (107), and a QAM signal transmitted to each subcarrier is demodulated.

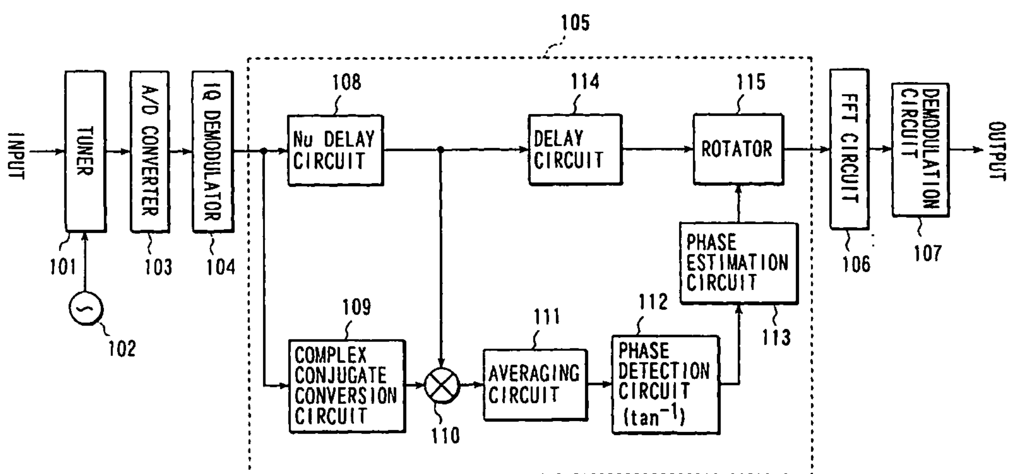

FIG. 2

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Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present invention relates to an orthogonal frequency division multiplexing (referred to as OFDM hereinafter) signal receiving apparatus for receiving an OFDM signal a one-symbol interval of which is constituted of a guard interval and an effective symbol interval and, more particularly, to a technique of suppressing a phase noise in a received signal.

[0002] A digital modulation system has recently been developed widely for transmission of voice and video signals. Especially an OFDM modulation system which overcomes a multipath interference becomes a focus of attention in a terrestrial digital broadcast. Prior art of the present invention will now be described.

[0003] An OFDM signal is susceptible to a phase noise since it is generated by multiplexing the frequencies of a number of subcarriers. A consumer-oriented receiver therefore has a serious problem of degrading a bit error rate due to a phase noise of a local oscillator of a tuner.

[0004] There are two influences of phase noise upon an OFDM signal. One is a phase variation of subcarriers generated by low-frequency components of the phase noise. This is called a common phase error (CPE) since all the subcarriers are varied at the same angle. The other is an inter-carrier interference (ICI) in which the SNR of carriers is degraded due to an interference of phase noise of other subcarriers. These influences greatly depend upon a spectrum of phase noise and an interval between subcarriers.

[0005] As a method of preventing the above characteristics from being degraded, J.H. Stott, "The DVB Terrestrial (DVB-T) Specification and Its Implementation in A Practical Modem," IBC, Sept., 1996 describes a method of eliminating a CPE using a continual pilot (CP) defined by DVB-T. FIG. 1 illustrates the constitution of a prior art OFDM signal receiving apparatus which is based on the contents of the technical literature.

[0006] Referring to FIG. 1, an input signal is frequency-converted to a signal having an IF (intermediate frequency) by a tuner 11 and a local oscillator 12. This signal is converted to a digital signal by an A/D converter 13 and then to a complex base-band signal by an IQ demodulator 14. A signal output from the IQ demodulator 14 is supplied to an FFT (Fast Fourier transform) circuit 15. The FFT circuit 15 removes an effective symbol interval (the number of samples: Nu) from a one-symbol interval of the OFDM signal to execute FFT processing (conversion of the effective symbol interval from a signal of time region to that of frequency region), thereby obtaining received data of each subcarrier.

[0007] The above-described CPE and ICI are caused on the output of the FFT circuit 15 due to a phase noise of the local oscillator 12. A CPE elimination circuit 16 eliminates a CPE of each subcarrier. An output signal of the circuit 16 is sent to a demodulation circuit 17, and a QAM signal transmitted to each subcarrier is demodulated and output therefrom.

[0008] The configuration and operation of the CPE elimination circuit 16 will be described further.

[0009] A signal having a fixed amplitude and a fixed phase is transmitted to a plurality of subcarriers having a predetermined frequency under the DVB-T standard. This is a CP (continual pilot) signal. The CP signal is branched off from the received data output from the FFT circuit 15 and converted to one in complex conjugate form in a complex conjugate conversion circuit 19. The signal is then supplied to a complex multiplier 20. The complex multiplier 20 is supplied with a one-symbol-old CP signal through an Nu delay circuit 18. In other words, the complex multiplier 20 multiplies the current received data and one-symbol-old data of the CP signals having the same frequency (the CP signals have only the effective symbol since they have been subjected to the FFT processing) to detect a phase variation from the one-symbol-old CP signal.

[0010] An output of the complex multiplier 20 is transmitted to an averaging circuit 21. The circuit 21 averages detection results of a plurality of CP signals to eliminate noise components. The averaging circuit 21 supplies a complex signal to a phase detection ($\tan^{-1}$) circuit 22, and the circuit 22 detects a phase of the complex signal. This detected phase corresponds to a phase variation common to the subcarriers generated by phase noise, i.e., a CPE. An output of the phase detection circuit 22 is supplied to an accumulator 23 and the detected phases are accumulated therein. An output of the accumulator 23 is sent to a rotator 24 and a one-symbol-old signal is rotated reversely. The CPE can thus be eliminated from the output signal of the TFT circuit.

[0011] As described above, the OFDM signal receiving apparatus shown in FIG. 1 is capable of eliminating a CPE due to a phase noise. However, when the low-frequency components of spectrum of the phase noise are large, an ICI suddenly increases as a frequency interval between subcarriers becomes narrow like an OFDM signal of 8K carrier. Therefore, only the CPE elimination has little effect on the improvement of a bit error rate. These circumstances are caused by not only the phase noise of the tuner but also the Doppler effect caused when a movable unit receives a signal.

[0012] It is accordingly an object of the present invention to provide an OFDM signal receiving apparatus which resolves the above problem and suppresses an ICI as well as a CPE to prevent a bit error rate due to a phase noise from being degraded.

[0013] In order to attain the above object, the present invention has the following characteristic means.

[0014] According to a first aspect of the present invention, an OFDM signal receiving apparatus for receiving an

OFDM (orthogonal frequency division multiplexing) signal a one-symbol interval of which is constituted of a guard interval (whose sample number is Ng) and an effective symbol interval (whose sample number is Nu), converting the OFDM signal into a complex base-band OFDM signal, and demodulating the complex base-band OFDM signal to obtain symbol data, comprises: first carrier phase variation detection means for detecting a carrier phase variation $\Delta\theta$ (m) per Nu sample in the m-th received symbol, using a signal S(m,n) at the n-th sample point ($0 \leqq n \leqq Ng-1$) within the guard interval of the m-th received symbol in the complex base-band OFDM signal and a signal S(m,n+Nu) at a sample point within the effective symbol interval which is delayed by Nu sample from the signal S(m,n); carrier phase estimation means for estimating a carrier phase θ^(m+1,0) at the head of the (m+1)-th received symbol from the carrier phase variation $\Delta\theta$ (m) output from the first carrier phase variation detection means and a carrier phase θ^(m,0) at the head of the m-th received symbol, and estimating all carrier phases θ^(m,n) ($0 \leqq n \leqq Ng+Nu-1$) within the m-th received symbol from carrier phases at the heads of at least m-th and (m+1)-th two continuous received symbols; phase variation correction means for correcting a phase variation in received signal by rotating signals S(m,n) ($0 \leqq n \leqq Ng+Nu-1$), located at all sample points of the m-th received symbol, by -θ^(m,n) using a signal output from the carrier phase estimation means; time-to-frequency region conversion means for converting an effective symbol interval within an output of the phase variation correction means from a signal of a time region to a signal of a frequency region to demodulate data of each subcarrier in the OFDM signal; and demodulation means (107) for demodulating an output of the time-to-frequency region conversion means to obtain symbol data transmitted to each subcarrier.

[0015] According to a second aspect of the present invention, an OFDM signal receiving apparatus for receiving an OFDM (orthogonal frequency division multiplexing) signal a one-symbol interval of which contains at least a known phase modulation carrier in a known position and which is constituted of a guard interval (whose sample number is Ng) and an effective symbol interval (whose sample number is Nu), converting the OFDM signal into a complex base-band OFDM signal, and demodulating the complex base-band OFDM signal to obtain symbol data, comprises: first carrier phase variation detection means for detecting a carrier phase variation $\Delta\theta$(m) per Nu sample in the m-th received symbol, using a signal S(m,n) at the n-th sample point ($0 \leqq n \leqq Ng-1$) within the guard interval of the m-th received symbol in the complex base-band OFDM signal and a signal S(m,n+Nu) at a sample point within the effective symbol interval which is delayed by Nu sample from the signal S(m,n); carrier phase estimation means for estimating a carrier phase θ^(m+1,0) at the head of the (m+1)-th received symbol from the carrier phase variation $\Delta\theta$(m) output from the first carrier phase variation detection means and a carrier phase θ^(m,0) at the head of the m-th received symbol, and estimating all carrier phases θ^(m,n) ($0 \leqq n \leqq Ng+Nu-1$) within the m-th received symbol from carrier phases at the heads of at least m-th and (m+1)-th two continuous received symbols; first phase variation correction means for correcting a phase variation in received signal by rotating signals S(m,n) ($0 \leqq n \leqq Ng+Nu-1$), located at all sample points of the m-th received symbol, by -θ^(m,n) using a signal output from the carrier phase estimation means; time-to-frequency region conversion means for converting an effective symbol interval within an output of the first phase variation correction means from a signal of a time region to a signal of a frequency region to demodulate data of each subcarrier in the OFDM signal; second phase variation detection means for detecting a phase variation $\Delta\phi$(m) common to all subcarriers, based on time-to-frequency region converting results C(m,k) and C(m+1,k) of continuous two symbols, using the phase modulation carrier output from the time-to-frequency region conversion means; second phase variation correction means for rotating the time-to-frequency region converting result C(m,k) by -$\Delta\phi$(m) using an output of the second carrier phase variation detection means to eliminate the phase variation common to all the subcarriers; and demodulation means for demodulating an output of the time-to-frequency region conversion means to obtain symbol data transmitted to each of the subcarriers.

[0016] This summary of the invention does not necessarily describe all necessary features so that the invention may also be a sub-combination of these described features.

[0017] The invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of an example of a prior art OFDM signal receiving apparatus;
FIG. 2 is a block diagram of the constitution of an OFDM signal receiving apparatus according to a first embodiment of the present invention;
FIG. 3 is a view depicting both a format of one symbol of a base-band OFDM signal input to a phase noise suppression circuit of the apparatus shown in FIG. 2 and contents processed by the phase noise suppression circuit;
FIG. 4 is a graph showing a relationship between variations in carrier phase and linear interpolation within an OFDM symbol in the phase noise suppression circuit;
FIG. 5 is a block diagram of a specific example of the configuration of a carrier phase estimation circuit used in the OFDM signal receiving apparatus of the first embodiment;
FIG. 6 is a block diagram of another specific example of the configuration of the carrier phase estimation circuit; and
FIG. 7 is a block diagram of the constitution of an OFDM signal receiving apparatus according to a second embodiment of the present invention.

[0018] Embodiments of the present invention will now be described in detail with reference to the accompanying drawings.

[0019] FIG. 2 illustrates an OFDM signal receiving apparatus according to a first embodiment of the present invention. As shown in FIG. 2, an input signal is frequency-converted to a signal having an IF (intermediate frequency) by a tuner 101 and a local oscillator 102. This signal is converted to a digital signal by an A/D converter 103 and then to a complex base-band signal by an IQ demodulator 104. A phase noise suppression circuit 105 detects a phase variation of an output signal of the IQ demodulator 104 and corrects it to suppress a phase noise of the local oscillator 102. An output signal of the circuit 105 is supplied to an FFT circuit 106.

[0020] The FFT circuit 106 removes an effective symbol interval (the number of samples: Nu) from a one-symbol interval of the OFDM signal to execute FFT processing, thereby obtaining received data of each subcarrier. Since the phase noise of the local oscillator 102 is reduced by the phase noise suppression circuit 105 before the FFT processing, both a CPE and an ICI are reduced from the output of the FFT circuit 106. The output of the FFT circuit 106 is sent to a demodulation circuit 107, and a QAM signal transmitted to each subcarrier is demodulated and output therefrom.

[0021] The configuration and operation of the phase noise suppression circuit 105 will be described further.

[0022] As illustrated in FIG. 3, one symbol of an OFDM signal is constituted of a guard interval (time interval Tg) and an effective symbol interval (time interval Tu). In the guard interval, part of an effective symbol is copied to prevent a multipath interference between symbols. A phase variation of carriers generated during the time interval Tu can thus be detected using these signals.

[0023] If a signal at the n-th ($0 \leqq n \leqq Ng-1$) sample point within the guard interval of the m-th received symbol in a complex base-band signal is expressed by S(m,n), an error vector e(m,n) indicative of carrier phase variation per time interval Tu can be obtained by the following equation:

$$e(m,n) = S^*(m,n) \cdot S(m,n+Nu) \quad (0 \leqq n \leqq Ng-1) \tag{1}$$

where Nu is the number of samples during the effective symbol interval, Ng is the number of samples during the guard interval, and S*(m,n) indicates a complex conjugate of S(m,n). The operation of equation (1) is performed by an Nu delay circuit 108, a complex conjugate conversion circuit 109 and a complex multiplier 110.

[0024] Error vectors e(m,n) of plural signals during the guard interval are averaged by the use of an averaging circuit 111 to eliminate an influence of noise from the signals. A result of the averaging is defined as error vector time e(m) in the m-th received symbol. For example, when all the signals during the guard interval are averaged, the error vector time e(m) is expressed by the following equation:

$$e(m) = \sum_{n=0}^{Ng-1} e(m,n) \quad \cdots (2)$$

[0025] The phase component of the error vector time e(m) obtained by the above equation (2) is defined as a carrier phase variation Δθ(m) per time interval Tu in the m-th received symbol. This carrier phase variation Δθ(m) is obtained from the following equation by means of a phase detection circuit ($\tan^{-1}$) 112:

$$\Delta\theta(m) = \tan^{-1}(\mathrm{Im}[e(m)]/\mathrm{Re}[e(m)]) \tag{3}$$

[0026] Using the above carrier phase variation Δθ(m), a carrier phase θ(m,n) within an OFDM symbol is estimated by a phase estimation circuit 113. A result of the estimation is θ^(m,n).

[0027] Using the output θ^(m,n) of the phase estimation circuit 113, a phase of output S(m,n) of a delay circuit 114 for timing adjustment is corrected by a rotator 115. When a phase-corrected signal is represented as S'(m,n), it is given by the following equation:

$$S'(m,n) = S(m,n) \cdot \exp[-j\theta\char`^(m,n)] \tag{4}$$

[0028] A method of estimating a carrier phase within the OFDM symbol, will be described with reference to FIG. 4.

[0029] FIG. 4 shows a relationship between variations of the carrier phase within the OFDM symbol and linear interpolation which will be described below. Using the carrier phase variation $\Delta\theta(m)$ obtained by the above equation (3), a carrier phase estimated value $\theta^\wedge(m+1,0)$ at the head of the (m+1)-th received symbol is calculated by the following equation. A carrier phase estimated value $\theta^\wedge(m,0)$ at the head of the m-th received symbol is one obtained when the (m-1)-th received symbol was processed.

$$\theta^\wedge(m+1,0) = \theta^\wedge(m,0)+(Ns/Nu)\cdot\Delta\theta(m) \qquad (5)$$

where Ns is the number of samples within a one-symbol interval.

[0030] All carrier phase estimated values $\theta^\wedge(m,n)$ within the m-th received symbol are obtained as follows by linear interpolation from both the carrier phase estimated values $\theta^\wedge(m,0)$ and $\theta^\wedge(m+1,0)$.

$$\begin{aligned}\theta^\wedge(m,n) &= (1-n/Ns)\cdot\theta^\wedge(m,0)+(n/Ns)\cdot\theta^\wedge(m+1,0)\\ &= \theta^\wedge(m,0)+(n/Nu)\cdot\Delta\theta(m) \qquad \ldots (6)\end{aligned}$$

[0031] FIG. 5 shows an example of the configuration of the phase estimation circuit 113 for estimating a carrier phase by the linear interpolation expressed by the equation (6). As shown in FIG. 5, a latch (D) circuit 201 is supplied with both a carrier phase variation $\Delta\theta(m)$ for every time interval Tu as input data and a symbol sync signal as a clock. The carrier phase variation $\Delta\theta(m)$ is thus latched in the latch circuit 201 with the timing of the head of the OFDM symbol. Since the carrier phase variation $\Delta\theta(m)$ is a value within the time interval Tu (the number of samples is Nu), it is multiplied by 1/Nu using a multiplier 202 to obtain a phase variation of one sample. Signals output from a multiplier 202 are accumulated in an accumulator 203 in units of sample. Consequently the all carrier phase estimated values $\theta^\wedge(m,n)$ within the symbol can be obtained by the linear interpolation using the equation (6).

[0032] An arbitrary value can be used as the initial value of the accumulator 203 when phase estimation is started (m = n = 0). The reason is as follows. A fixed offset, which is caused in a carrier phase estimated according to the initial value, can be corrected by a sync signal detection circuit constituting the demodulation circuit 107.

[0033] In the above equation (6), a carrier phase within a symbol is interpolated based on the carrier phase estimated values of the heads of continuous two symbols. If more phase data are used for interpolation, the carrier phase can be estimated with higher precision. For example, all the carrier phase estimated values $\theta^\wedge(m,n)$ within the m-th received symbol can be obtained from carrier phase estimated values $\theta^\wedge(m+1,0)$, $\theta^\wedge(m,0)$ and $\theta^\wedge(m-1,0)$ of heads of continuous three symbols, by the following equation:

$$\begin{aligned}\theta^\wedge(m,n) = {} & A(n/Ns)\cdot\theta^\wedge(m+1,0)+B(n/Ns)\cdot\theta^\wedge(m,0)\\ & +C(n/Ns)\cdot\theta^\wedge(m-1,0)(m) \qquad (7)\end{aligned}$$

[0034] In the above equation (7), A(n/Ns), B(n/Ns) and C(n/Ns) are polynomials for interpolation. Various processes such as Gauss interpolation are known as an interpolation algorithm.

[0035] FIG. 6 shows another example of the configuration of the phase estimation circuit 113 for estimating a carrier phase by the interpolation given by the equation (7). Referring to FIG. 6, a latch circuit 301 is supplied with both a carrier phase variation $\Delta\theta$ (m) for every time interval Tu as input data and a symbol sync signal as a clock. The carrier phase variation $\Delta\theta(m)$ is thus latched in the latch circuit 301 with the timing of the head of the m-th OFDM symbol. Since the carrier phase variation $\Delta\theta(m)$ is a value within the time interval Tu (the number of samples is Nu), it is multiplied by (Ng+Nu)/Nu using a multiplier 302 to obtain a phase variation of one OFDM symbol.

[0036] Signals output from a multiplier 302 are accumulated in an accumulator 303 in units of symbol. In other words, the output of the accumulator 303 is a carrier phase estimated value $\theta^\wedge(m+1,0)$ at the head of the next symbol or the (m+1)-th symbol. The outputs of latch circuits 304 and 305 are a carrier phase estimated value $\theta^\wedge(m,0)$ at the head of the m-th received symbol and a carrier phase estimated value $\theta^\wedge(m-1,0)$ at the head of the (m-1)-th received symbol, respectively.

[0037] The output signals of the accumulator 303 and latch circuits 304 and 305 are supplied to an interpolation circuit 306, and a sample number n within a symbol is supplied from a symbol counter 307 to the interpolation circuit 306. The circuit 306 computes carrier phase estimated values $\theta^\wedge(m+1,0)$, $\theta^\wedge(m,0)$ and $\theta^\wedge(m-1,0)$ at the heads of (m+1)-th, m-th and (m-1)-th received symbols and does all carrier phase estimated values $\theta^\wedge(m,n)$ within the m-th symbol

using the sample number n.

[0038] As described above, the phase estimation circuit shown in FIG. 6 is more complicated in signal processing and circuit arrangement than that shown in FIG. 5; however, the former circuit is capable of obtaining the carrier phase θ^(m,n) with higher precision.

[0039] In the circuit shown in FIG. 6, an arbitrary value can be used as the initial value of the accumulator 303 when phase estimation is started (m = 0). The reason is as follows. A fixed offset, which is caused in a carrier phase according to the initial value, can be corrected by a sync signal detection circuit constituting the demodulation circuit 107. Furthermore, in the circuit of FIG. 6, interpolation is made using three pieces of phase data, but it is evident that the interpolation can be done using more pieces of phase data.

[0040] FIG. 7 illustrates an OFDM signal receiving apparatus according to a second embodiment of the present invention. In the second embodiment, a CPE elimination circuit 401 is added to the apparatus of FIG. 2 and it is provided after the FFT circuit 106, as in the case of the prior art apparatus. Both a CPE and an ICI are decreased by suppressing a phase noise by a phase noise suppression circuit 105 before the FFT circuit 106, and the remaining CPE is eliminated by a CPE elimination circuit 401. The CPE elimination circuit 401 has the same configuration as that of the circuit 16 illustrated in FIG. 1, and includes an Nu delay circuit 402, a complex conjugate conversion circuit 403, a complex multiplier 404, an averaging circuit 405, a phase detection circuit ($\tan^{-1}$) 406, an accumulator 407 and a rotator 408. The operation thereof is the same as that of the circuit 16 shown in FIG. 1.

[0041] A CP signal is branched off from received data output from the FFT circuit 106 and converted to one in complex conjugate form in the complex conjugate conversion circuit 403. The signal is then supplied to the complex multiplier 404. The complex multiplier 404 is supplied with a one-symbol-old CP signal through the Nu delay circuit 402. The complex multiplier 404 multiplies the current received data and one-symbol-old data of the CP signals having the same frequency to detect a phase variation from the one-symbol-old CP signal.

[0042] An output of the complex multiplier 404 is supplied to the averaging circuit 405. The circuit 405 averages detection results of a plurality of CP signals to eliminate noise components. The averaging circuit 405 supplies a complex signal to the phase detection circuit 406, and the circuit 406 detects a phase of the complex signal. This detected phase corresponds to a phase variation common to the subcarriers generated by phase noise, i.e., a CPE. An output of the phase detection circuit 406 is supplied to the accumulator 407 and the detected phases are accumulated therein. An output of the accumulator 407 is sent to the rotator 408 and a one-symbol-old signal is rotated reversely. The CPE can thus be eliminated from the output signal of the TFT circuit 106.

[0043] With the above processing, the circuit of the second embodiment allows a degradation due to phase noise to be reduced more greatly than that of the first embodiment shown in FIG. 2.

[0044] In the above embodiments described above, a CP signal is contained in the symbol of an OFDM signal. The present invention is not limited to the CP signal. If there is a known phase modulation carrier (whose amplitude need not be fixed and which can be modulated) in a known position of the symbol, it can be used.

[0045] In the first and second embodiments shown in FIGS. 2 and 7, the QAM technique is used to modulate subcarriers. Even in a differential modulation technique such as DQPSK, the present invention can definitely be applied to such a configuration by replacing the sync signal detection circuit constituting the demodulation circuit 107 with a delay detection circuit.

[0046] As has been described above, according to the present invention, an OFDM signal receiving apparatus capable of reducing both a CPE and an ICI due to phase noise to prevent a bit error rate from being degraded, can be provided.

Claims

1. An OFDM signal receiving apparatus for receiving an OFDM (orthogonal frequency division multiplexing) signal a one-symbol interval of which is constituted of a guard interval (whose sample number is Ng) and an effective symbol interval (whose sample number is Nu), converting the OFDM signal into a complex base-band OFDM signal, and demodulating the complex base-band OFDM signal to obtain symbol data, characterized by comprising:

    first carrier phase variation detection means (108, 109, 110, 111, 112) for detecting a carrier phase variation Δθ(m) per Nu sample in the m-th received symbol, using a signal S(m,n) at the n-th sample point ($0 \leqq n \leqq$ Ng-1) within the guard interval of the m-th received symbol in the complex base-band OFDM signal and a signal S(m,n+Nu) at a sample point within the effective symbol interval which is delayed by Nu sample from the signal S(m,n);

    carrier phase estimation means (113) for estimating a carrier phase θ^(m+1,0) at the head of the (m+1)-th received symbol from the carrier phase variation Δθ(m) output from the first carrier phase variation detection means and a carrier phase θ^(m,0) at the head of the m-th received symbol, and estimating all carrier phases

$\hat{\theta}(m,n)$ $(0 \leqq n \leqq Ng+Nu-1)$ within the m-th received symbol from carrier phases at the heads of at least m-th and (m+1)-th two continuous received symbols;

phase variation correction means (114, 115) for correcting a phase variation in received signal by rotating signals $S(m,n)$ $(0 \leqq n \leqq Ng+Nu-1)$, located at all sample points of the m-th received symbol, by $-\hat{\theta}(m,n)$ using a signal output from the carrier phase estimation means;

time-to-frequency region conversion means (106) for converting an effective symbol interval within an output of the phase variation correction means from a signal of a time region to a signal of a frequency region to demodulate data of each subcarrier in the OFDM signal; and

demodulation means (107) for demodulating an output of the time-to-frequency region conversion means to obtain symbol data transmitted to each subcarrier.

2. An OFDM signal receiving apparatus for receiving an OFDM (orthogonal frequency division multiplexing) signal a one-symbol interval of which contains at least a known phase modulation carrier in a known position and which is constituted of a guard interval (whose sample number is Ng) and an effective symbol interval (whose sample number is Nu), converting the OFDM signal into a complex base-band OFDM signal, and demodulating the complex base-band OFDM signal to obtain symbol data, characterized by comprising:

first carrier phase variation detection means (108, 109, 110, 111, 112) for detecting a carrier phase variation $\Delta\theta(m)$ per Nu sample in the m-th received symbol, using a signal $S(m,n)$ at the n-th sample point $(0 \leqq n \leqq Ng-1)$ within the guard interval of the m-th received symbol in the complex base-band OFDM signal and a signal $S(m,n+Nu)$ at a sample point within the effective symbol interval which is delayed by Nu sample from the signal $S(m,n)$;

carrier phase estimation means (113) for estimating a carrier phase $\hat{\theta}(m+1,0)$ at the head of the (m+1)-th received symbol from the carrier phase variation $\Delta\theta(m)$ output from the first carrier phase variation detection means and a carrier phase $\hat{\theta}(m,0)$ at the head of the m-th received symbol, and estimating all carrier phases $\hat{\theta}(m,n)$ $(0 \leqq n \leqq Ng+Nu-1)$ within the m-th received symbol from carrier phases at the heads of at least m-th and (m+1)-th two continuous received symbols;

first phase variation correction means (114, 115) for correcting a phase variation in received signal by rotating signals $S(m,n)$ $(0 \leqq n \leqq Ng+Nu-1)$, located at all sample points of the m-th received symbol, by $-\hat{\theta}(m,n)$ using a signal output from the carrier phase estimation means;

time-to-frequency region conversion means (106) for converting an effective symbol interval within an output of the first phase variation correction means from a signal of a time region to a signal of a frequency region to demodulate data of each subcarrier in the OFDM signal;

second phase variation detection means (402, 403, 404, 405, 406, 407) for detecting a phase variation $\Delta\phi(m)$ common to all subcarriers, based on time-to-frequency region converting results $C(m,k)$ and $C(m+1,k)$ of continuous two symbols, using the phase modulation carrier output from the time-to-frequency region conversion means;

second phase variation correction means (408) for rotating the time-to-frequency region converting result $C(m,k)$ by $-\Delta\phi(m)$ using an output of the second carrier phase variation detection means to eliminate the phase variation common to all the subcarriers; and

demodulation means (107) for demodulating an output of the time-to-frequency region conversion means to obtain symbol data transmitted to each of the subcarriers.

3. The OFDM signal receiving apparatus according to one of claims 1 and 2, characterized in that the first carrier phase variation detection means includes:

delay means (108) for delaying the complex base-band OFDM signal by Nu sample;

complex conjugate conversion means (109) for generating a complex conjugate signal of the complex base-band OFDM signal;

complex multiplying means (110) for multiplying an output of the delay means and an output of the complex conjugate conversion means;

averaging means (111) for averaging a plurality of samples of n $(0 \leqq n \leqq Ng-1)$ multiplication results within the guard interval of the m-th received symbol, which are output from the complex multiplying means, the number of the samples being not larger than Ng; and

phase detecting means (112) for detecting an output of the averaging means.

4. The OFDM signal receiving apparatus according to one of claims 1 and 2, characterized in that the carrier phase estimation means estimates all carrier phases $\theta(m,n)$ within the m-th received symbol from carrier phases $\hat{\theta}$

(m+1,n) and θ^(m,0) at the heads of continuous two symbols, and includes:

latch means (201) for latching the carrier phase variation Δϕ(m) with timing of the head of the symbol;
multiplying means (202) for multiplying an output of the latch means by a coefficient 1/Nu; and
accumulation means (203) for accumulating outputs of the multiplying means in units of sample.

5. The OFDM signal receiving apparatus according to one of claims 1 and 2, characterized in that the carrier phase estimation means estimates all carrier phases θ (m,n) within the m-th received symbol from carrier phases θ^(m+1,0), θ^(m, 0), ..., θ^(m-1+2,0) at the heads of continuous l symbols (l ≧ 3), and includes:

first latch means (301) for latching the carrier phase variation Δϕ(m) with timing of the head of the symbol;
multiplying means (302) for multiplying an output of the first latch means by a coefficient (Ng+Nu)/Nu;
accumulation means (303) for accumulating outputs of the multiplying means with timing of the head of the symbol;
(l-1) second latch means (304, 305) for latching an output of the accumulation means within a (l-1) symbol interval;
a symbol counter (307) for generating a value n indicative of a sample position in the received symbol; and
interpolation means (306) for interpolating all carrier phases θ (m,n) within the m-th received symbol using an output θ^(m+1,0) of the accumulation means, outputs θ^(m, 0), ..., θ^(m-1+2,0) of the (l-1) second latch means, and an output n of the symbol counter.

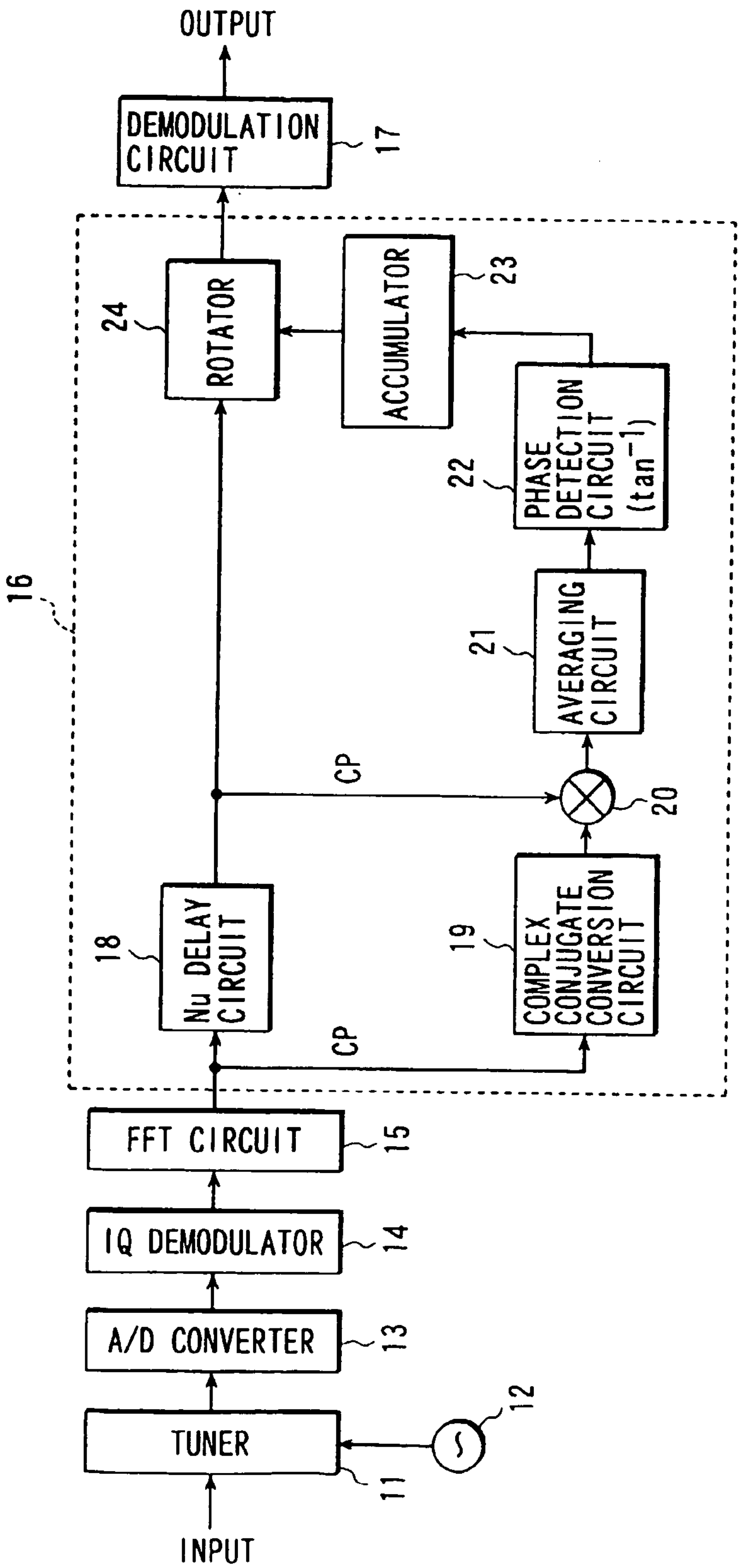


FIG. 1

(PRIOR ART)

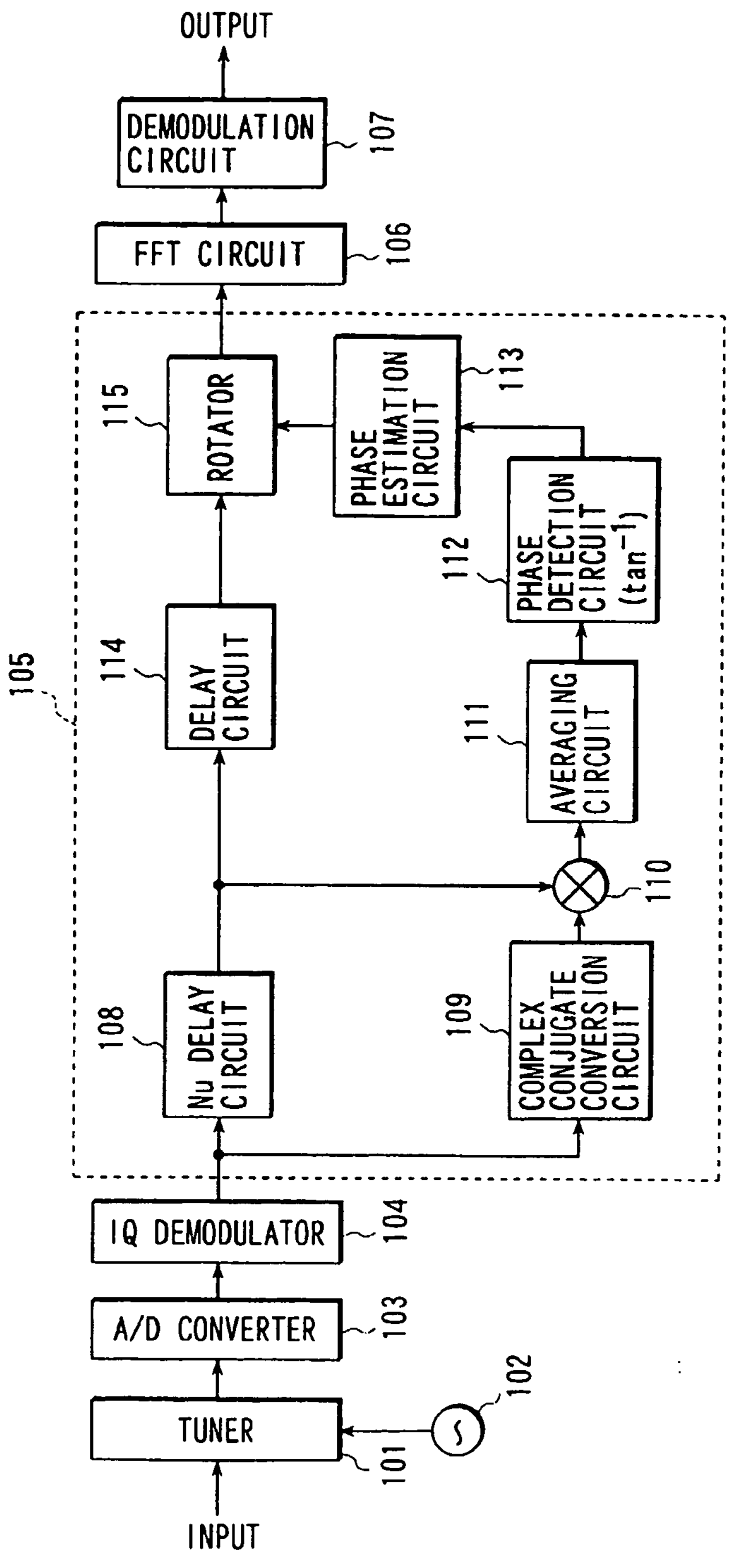

OUTPUT
DEMODULATION CIRCUIT
107
FFT CIRCUIT
106
ROTATOR
115
PHASE ESTIMATION CIRCUIT
113
PHASE DETECTION CIRCUIT (tan^{-1})
112
DELAY CIRCUIT
114
105
AVERAGING CIRCUIT
111
110
Nu DELAY CIRCUIT
108
COMPLEX CONJUGATE CONVERSION CIRCUIT
109
IQ DEMODULATOR
104
A/D CONVERTER
103
102
TUNER
101
INPUT

FIG. 2

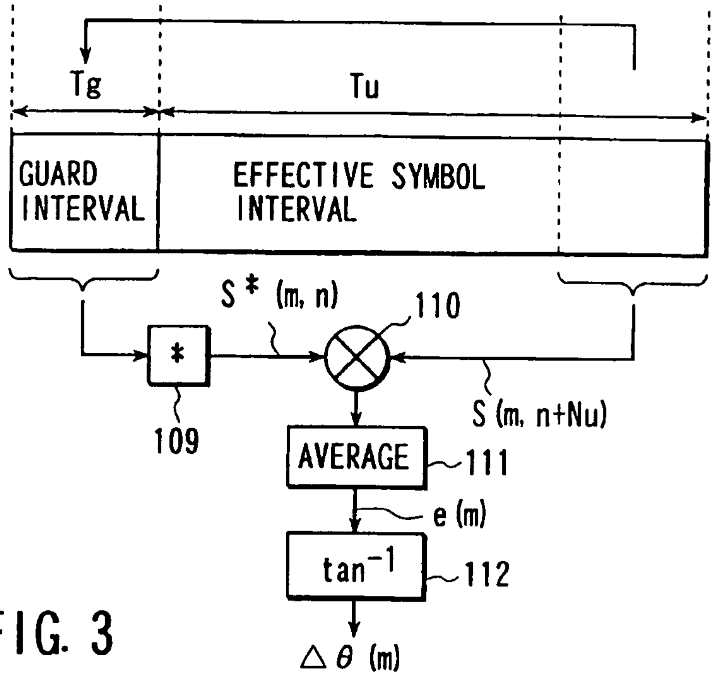


FIG. 3

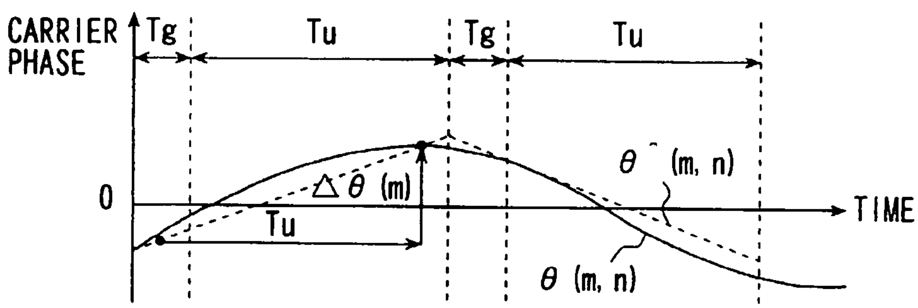


FIG. 4

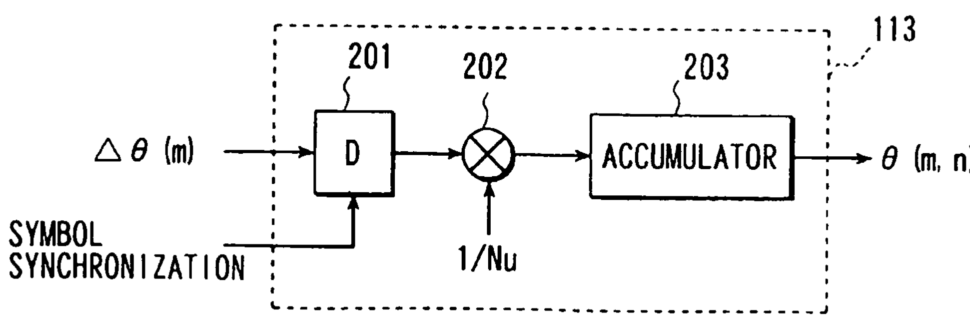
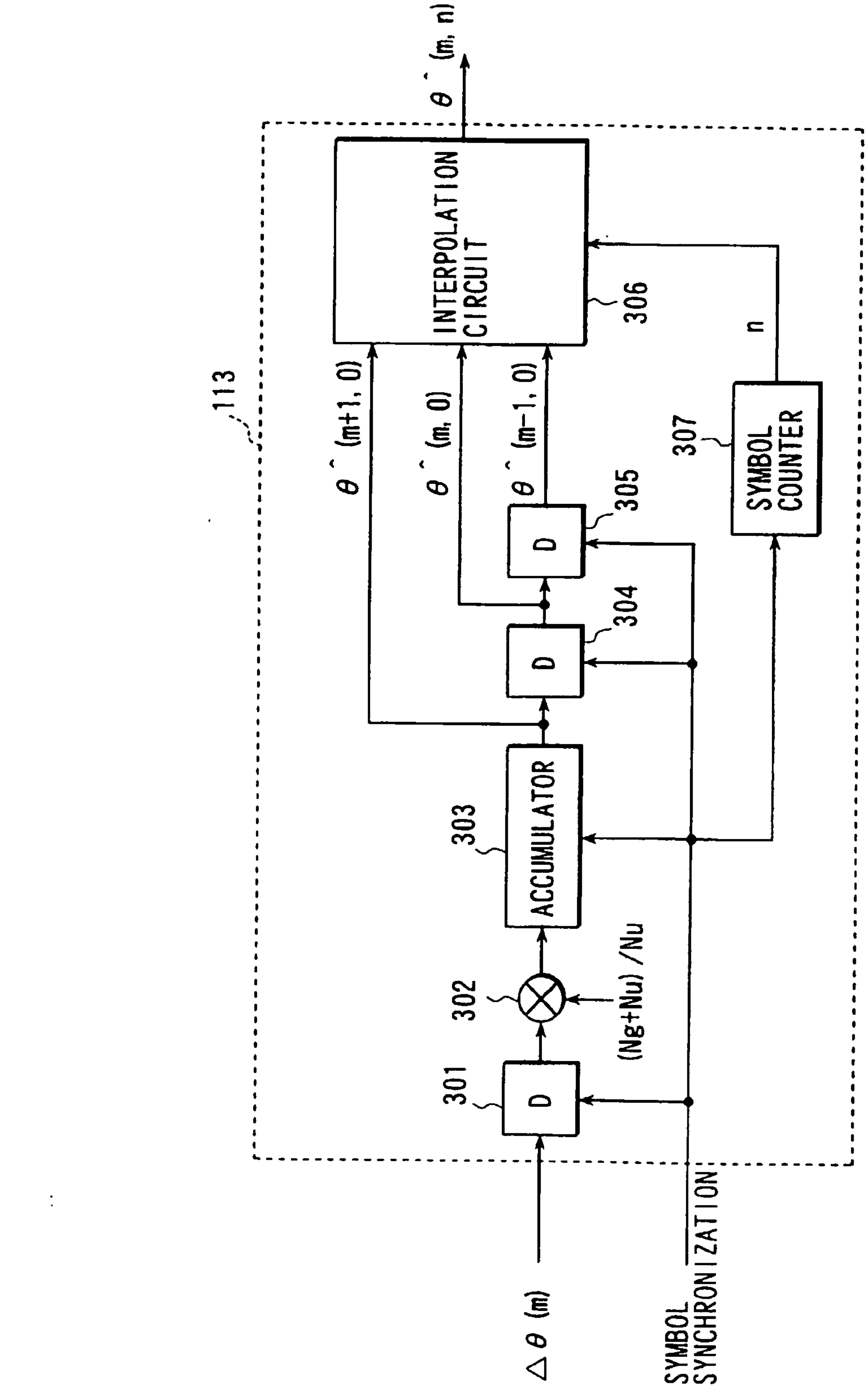


FIG. 5



θ^ (m, n)
113
INTERPOLATION CIRCUIT
306
θ^ (m+1, 0)
θ^ (m, 0)
θ^ (m−1, 0)
n
307
SYMBOL COUNTER
305
D
304
D
303
ACCUMULATOR
302
(Ng+Nu) /Nu
301
D
Δθ (m)
SYMBOL SYNCHRONIZATION

FIG. 6

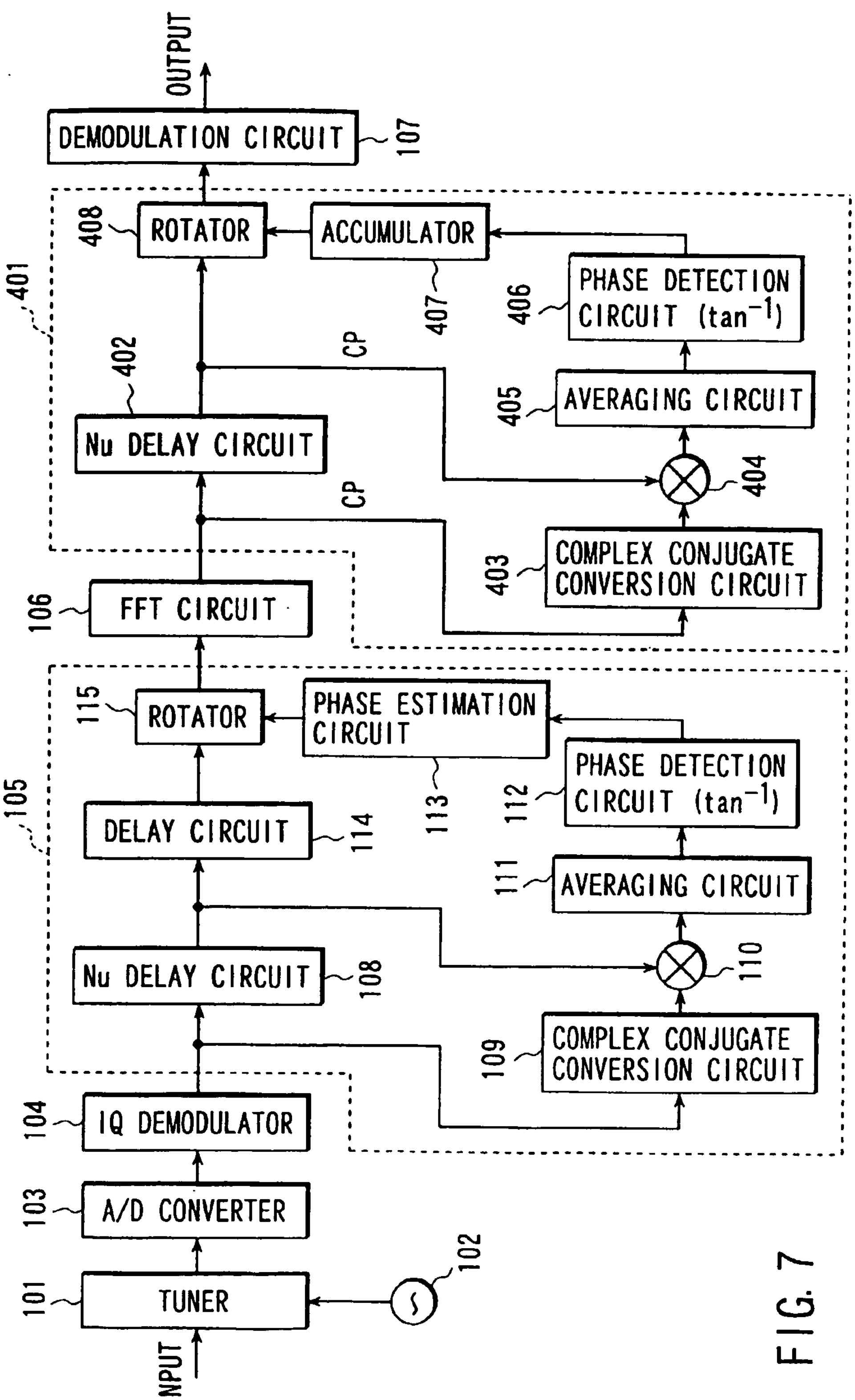

OUTPUT
DEMODULATION CIRCUIT
107
401
408
ROTATOR
ACCUMULATOR
407
PHASE DETECTION
CIRCUIT (tan^{-1})
406
402
CP
AVERAGING CIRCUIT
405
Nu DELAY CIRCUIT
404
CP
COMPLEX CONJUGATE
CONVERSION CIRCUIT
403
106
FFT CIRCUIT
115
ROTATOR
PHASE ESTIMATION
CIRCUIT
113
PHASE DETECTION
CIRCUIT (tan^{-1})
112
105
DELAY CIRCUIT
114
AVERAGING CIRCUIT
111
Nu DELAY CIRCUIT
108
110
COMPLEX CONJUGATE
CONVERSION CIRCUIT
109
104
IQ DEMODULATOR
103
A/D CONVERTER
102
101
TUNER
INPUT

FIG. 7